Systems Engineering, Knowledge Management, Artificial Intelligence, the Semantic Web and Operations Research

Rod Staker

Systems-of-Systems Group

Joint Systems Branch

Defence Systems Analysis Division

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **01 OCT 2003**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Systems Engineering, Knowledge Management, Artificial Intelligence, the Semantic Web and Operations Research**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **DSTO Defence Systems Analysis Division**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001929. Proceedings, Held in Sydney, Australia on July 8-10, 2003., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**24**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Outline

- Introduction

- Systems Theory

- Systems Architecture Representation

- Aggregating Stakeholder Preferences

- Defence Systems Engineering

- Example (ASBM)

- Future Work

- Conclusion

Basic Systems Theory

- Systems are characterised by
    - purposes
    - components
    - attributes of components
    - relationships between components
- Components can be sub-systems, themselves composed of components, etc.
    - results in subsystem / component hierarchy
- *Conceptual* system vs. physical "system" *(asset configuration)*

Systems Architecture

- Systems architecture
  - abstract representation of *ensemble* of asset configurations
- Architectural Description Frameworks
  - US DoD C4ISR Architecture Framework
  - IEEE Std 1471-2000 Recommended Practice for Architectural Description Software-Intensive Systems
  - Australian Defence Architecture Framework
- Question: How may architecture descriptions be rigorously articulated?

Semantic Web

- Builds on World Wide Web technology

- Present web permits exchange of content

  - NOT underlying meaning: must be inferred by human user

- Semantic Web allows formal representation of hierarchies and relationships (as used in SE)

- Knowledge distributed across network

- Based on graph theory, uses navigation metaphor

- Uses RDF and XML W3C standards

Web Ontology Language (OWL)

- Description Logic used to formally articulate concepts

  - combines Boolean algebra and relation algebra

- Boolean algebra - allows hierarchies (lattices) to be formally specified

  - indirectly implied inclusions automatically derivable

- Relation algebra - describes *linkages* between concepts at various levels hierarchy

  - helps determine additional inclusions that may validly be inferred

Example from C4ISR AF

- IMPLIES
  - Need line
    - AND
      - EXACTLY 1
        - provided by
        - Operational node
      - EXACTLY 1
        - used by
        - Operational node
      - EXACTLY 1
        - item needed
        - Operational information element

Abductive Inference

- Deduction, Induction and *Abduction*: distinct modes of inference

- Deduction

  - derive new facts from existing facts using predetermined rules

- Induction

  - infer general rules from facts

- Abduction

  - given rules and some facts, suggest additional facts that would "best" explain the given facts

Defence Force Systems Engineering

Present (legacy)

F-111
F/A-18
ANZAC
Collins
JORN

Best Prospects Decision

JSF
AW Destroyer
UAV
etc.

Next (alternatives)

**Possible Futures (many)**

Evolution

UCAV
Robot Warriors
Swarms
etc

Decision Support

- – Human beings competent to deal with ~ 7 alternatives at once

- – Use automated methods to cull decision options down to a few best

  - – stakeholders and decision-makers then give these close scrutiny

- – Take "best" to mean "most credible"

- – Employ Bayesian Belief Network techniques to perform *credibilistic* abductive reasoning

- – Include future epochs so that the impacts of future eventualities are incorporated

Concept of Use
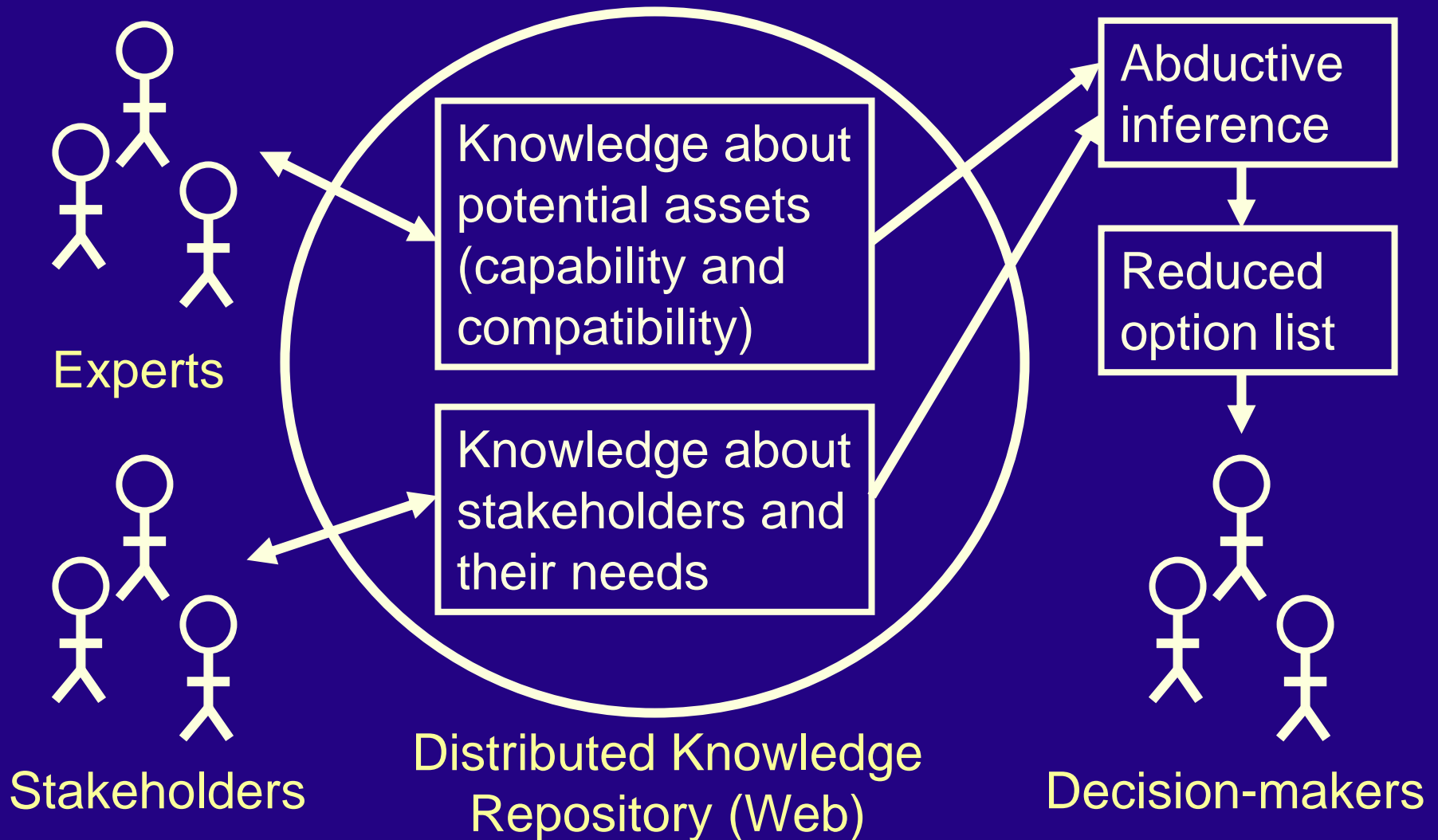
Aerospace Surveillance and Battle Management

- Projects
    - Air 5077 AEW&C
    - Air 5333 Vigilare
    - Air 5405 Mobile Sector Operations Centre
    - Joint 117 Ground Based Air Defence
    - Joint 2025 JORN
    - Joint 2044 Space Based Surveillance
    - Joint 2062 Global Hawk
- Legacy Assets
    - 114MCRU, Air Defence
- Stakeholders, Epochs

Top Level Description Logic Expressions

- IMPLIES 100% ASBM capability
  - AND
    - Air surveillance
    - Airborne Comms Relay
    - Point Defence
- IMPLIES Air surveillance
  - AND
    - Long range surveillance
    - Medium range surveillance
- IMPLIES Point Defence
  - AND
    - Local area surveillance
   - Weapons system

Additional Expressions

- IMPLIES 70% ASBM capability
  - AND
    - Air surveillance
    - Point Defence
- IMPLIES Long range surveillance
  - OR
    - JORN (Upgraded)
    - Space-based surveillance (Present)
- IMPLIES Medium range surveillance
  - OR
    - UAV (Present)
    - AEW&C (Present)
- EQUALS JORN (Upgraded)
  - JORN AND (SOME has_condition Upgraded)
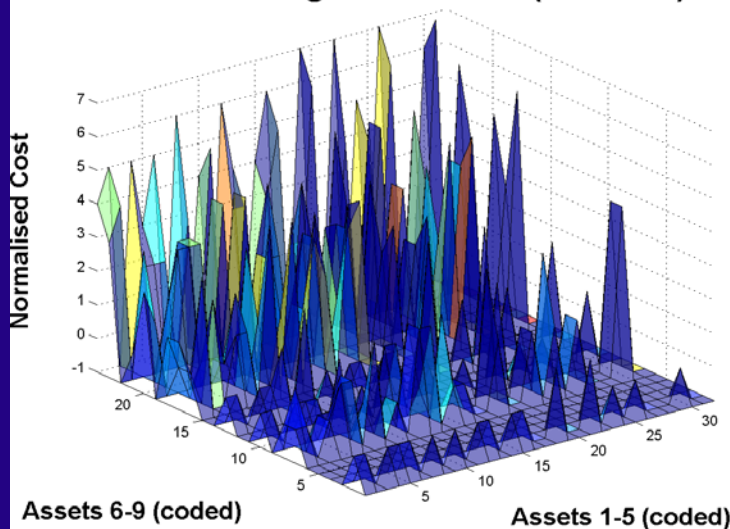
Value Network for Warfighter
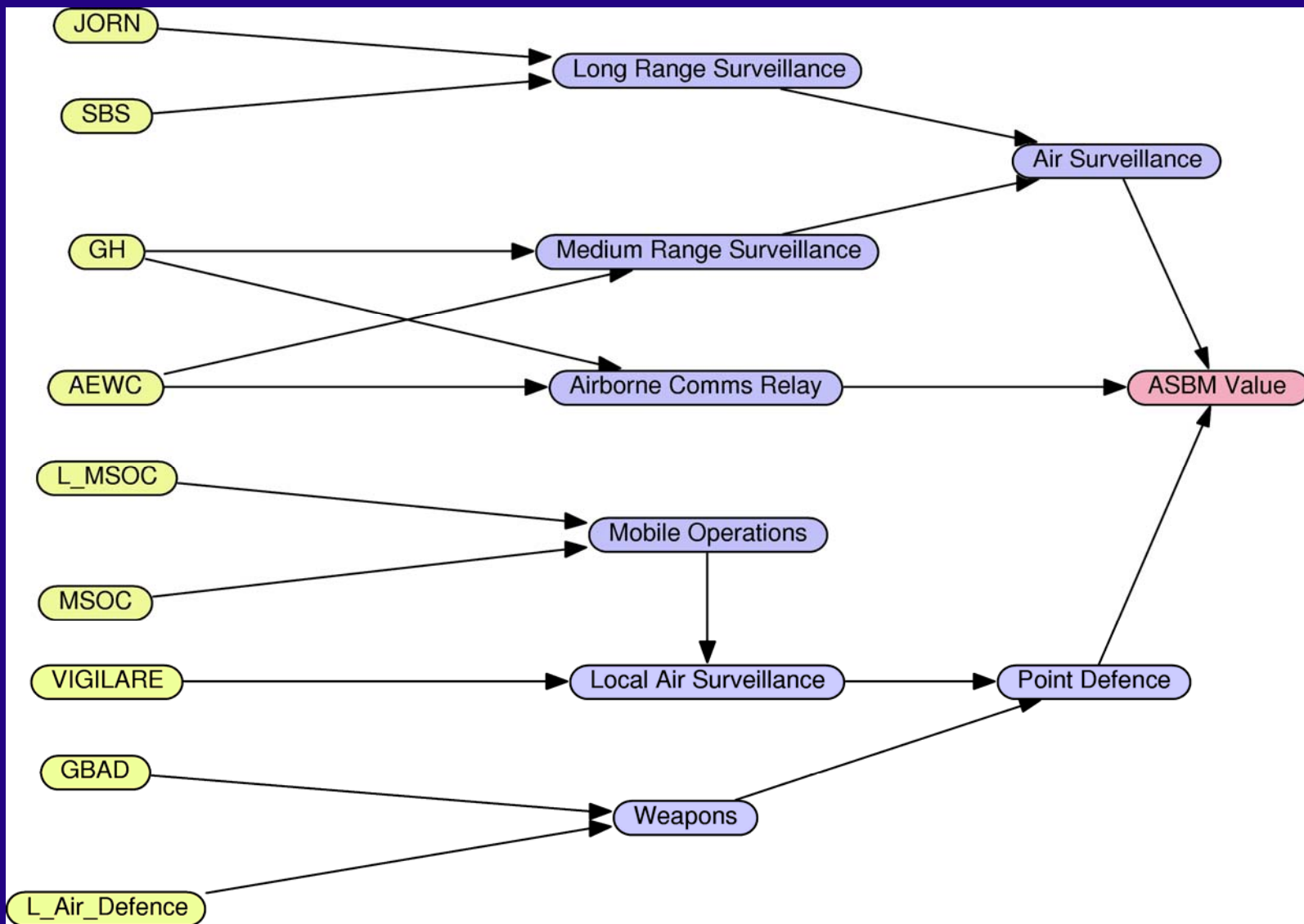
Warfighter Preference

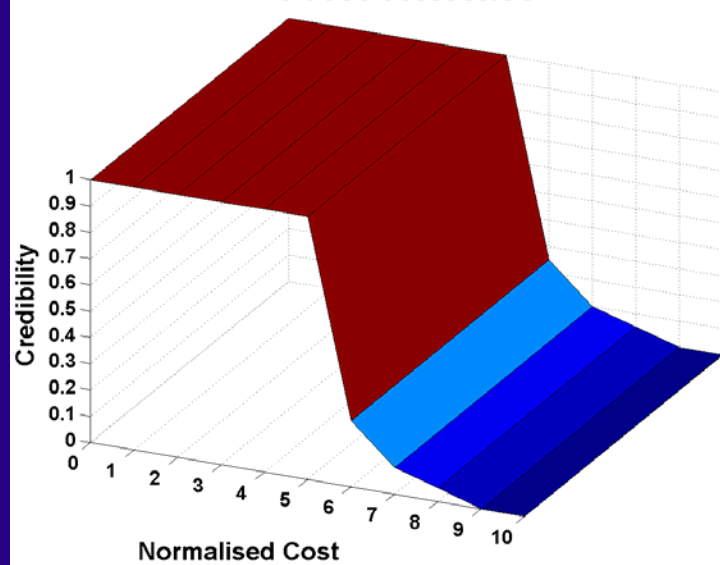Asset Configuration Prior Credibility for Period 1
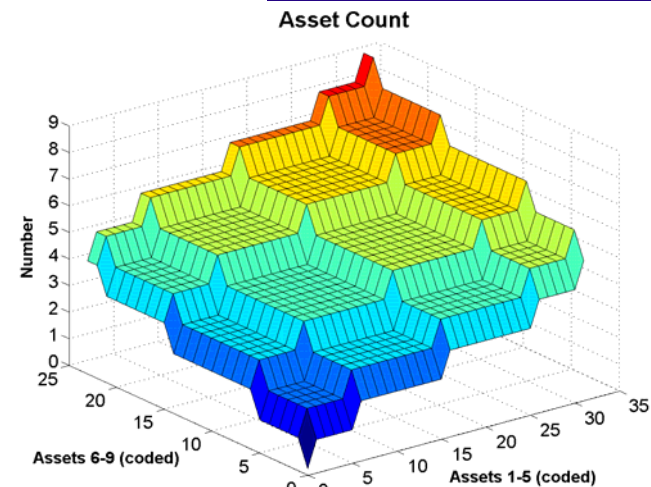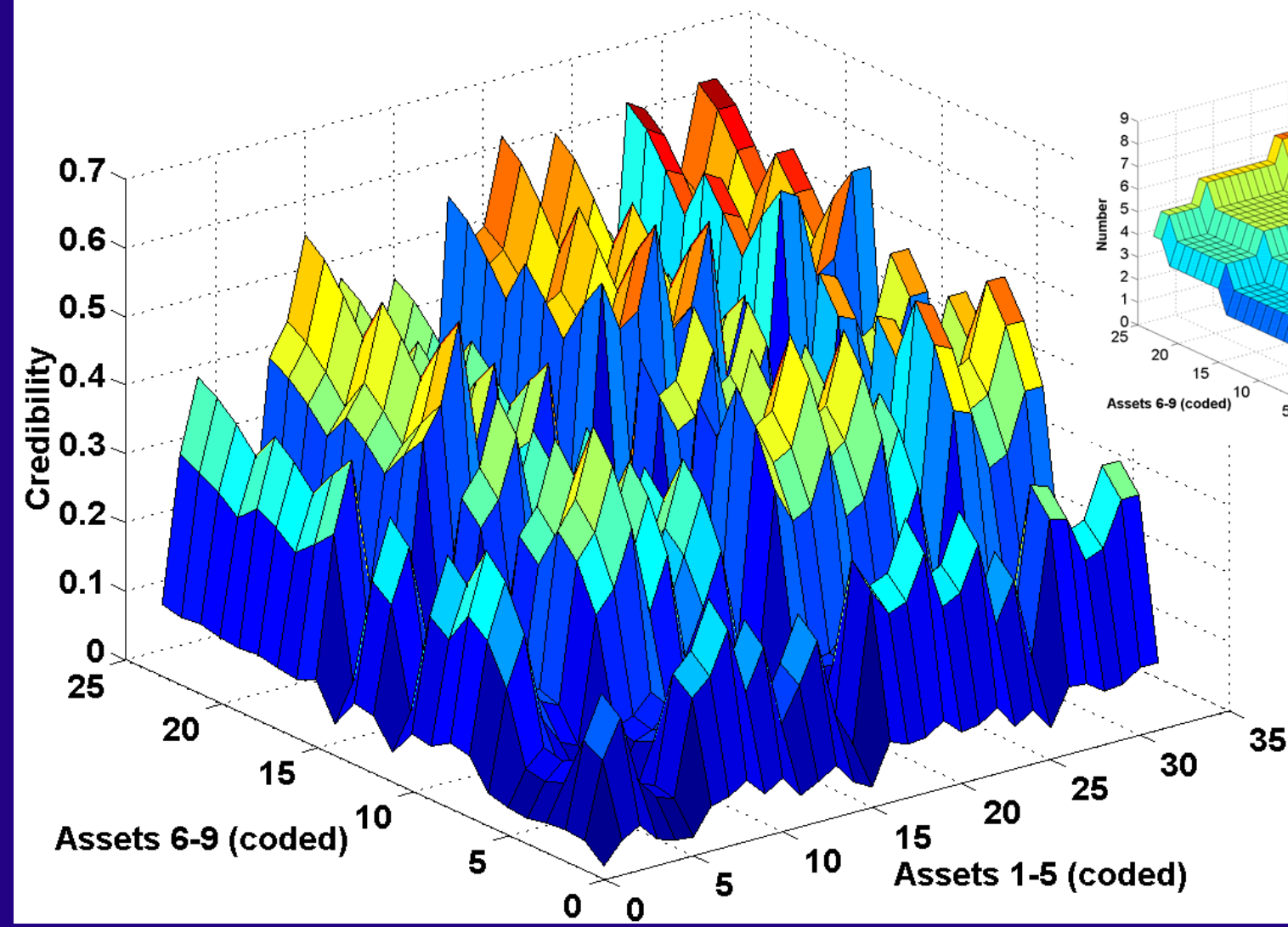
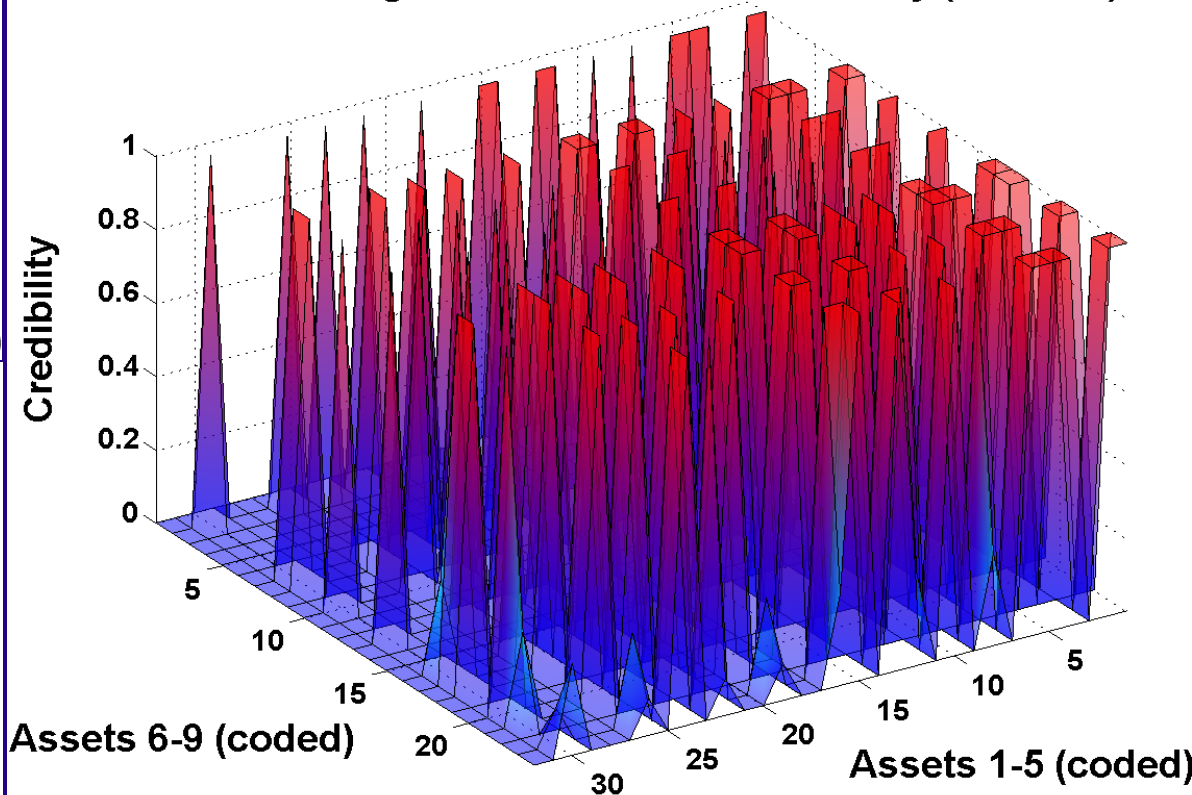# Finance Manager Preference

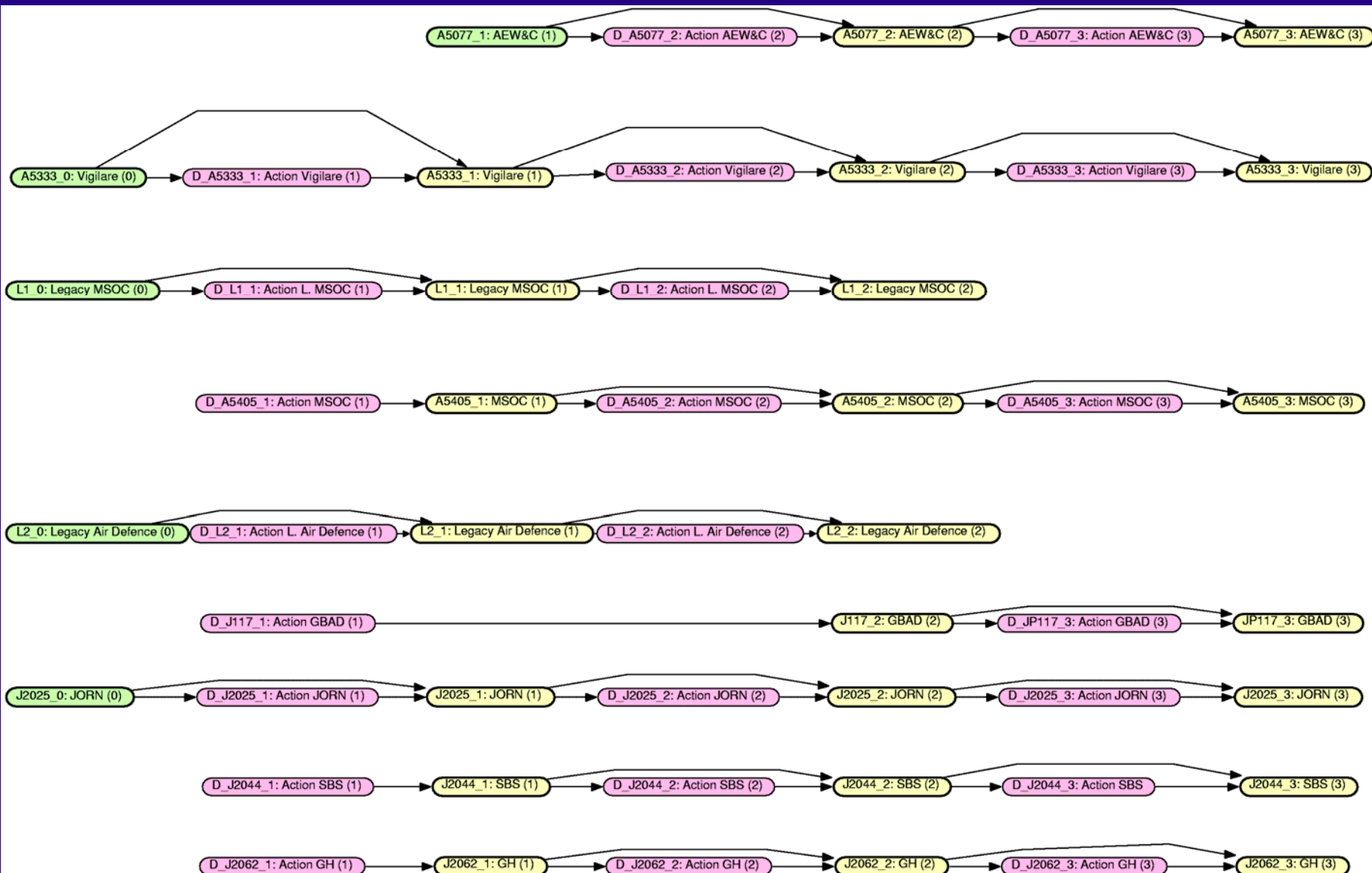
Asset Configuration Cost (Period 1)

Cost Preference

Asset Configuration Cost Prior Credibility (Period 1)

Temporal Evolution of Asset Configuration

ASBM Marginal Credibility Map

Asset / Period	Period 0	Period 1	Period 2	Period 3
AEW&C	Absent / Present	Absent / Present	Absent / Original / Augmented by 2 / Augmented by 3	Absent / Original / Augmented by 2 / Augmented by 3
Vigilare	Absent / Present	Absent / Present	Absent / Original / Enhanced	Absent / Original / Enhanced
L. MSOC	Absent / Present	Absent / Present	Absent / Present	Absent / Present
MSOC	Absent / Present	Absent / Present	Absent / Present	Absent / Present
L. Air Defence	Absent / Present	Absent / Present	Absent / Present	Absent / Present
GBAD	Absent / Present	Absent / Present	Absent / Present	Absent / Present
JORN	Absent / Present	Absent / Original / Upgraded 1	Absent / Original / Upgraded 1	Absent / Original / Upgraded 1 / Upgraded 2
SBS	Absent / Present	Absent / Present	Absent / Present	Absent / Original / Upgraded
GH	Absent / Present	Absent / Present	Absent / Present	Absent / Present

Range	Colour
0–0.1	
0.1–0.2	
0.2–0.3	
0.3–0.4	
0.4–0.5	
0.5–0.6	
0.6–0.7	
0.7–0.8	
0.8–0.9	
0.9–1.0	
1.0	

ASBM Best Prospects Trajectory Map

Asset / Period	Period 0	Period 1	Period 2	Period 3
AEW&C	Absent Present	Absent Present	Absent Original Augmented by 2 Augmented by 3	Absent Original Augmented by 2 Augmented by 3
Vigilare	Absent Present	Absent Present	Absent Original Enhanced	Absent Original Enhanced
L. MSOC	Absent Present	Absent Present	Absent Present	Absent Present
MSOC	Absent Present	Absent Present	Absent Present	Absent Present
L. Air Defence	Absent Present	Absent Present	Absent Present	Absent Present
GBAD	Absent Present	Absent Present	Absent Present	Absent Present
JORN	Absent Present	Absent Original Upgraded 1	Absent Original Upgraded 1	Absent Original Upgraded 1 Upgraded 2
SBS	Absent Present	Absent Present	Absent Present	Absent Original Upgraded
GH	Absent Present	Absent Present	Absent Present	Absent Present

Future Work

- Additional case studies

- Build acquisition decision-support models for ADF

- Support Defence Capability Plan development

- Develop active distributed knowledge repository

    - semantic Web technology

    - "industry-standard" products

Conclusion

- Defence Force Systems Engineering
- Semantic Web system knowledge repository
- Artificial intelligence uncertain reasoning techniques
  - find promising alternative designs for closer inspection
  - alleviate task confronting decision-makers
  - may yield improved decision quality and consistency
- Future application to Defence Capability Plan anticipated

Questions?